Energy Research and Development Division
FINAL PROJECT REPORT

CLIMATE ADAPTATION PLANNING IN CALIFORNIA USING GOOGLE EARTH®/weADAPT®: A PILOT STUDY

Prepared for: California Energy Commission
Prepared by: Stockholm Environment Institute

STOCKHOLM ENVIRONMENT INSTITUTE

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Climate Adaptation Planning in California Using Google Earth ®/weADAPT®: A Pilot Study is the final report for the Climate Adaptation Planning in California Using Google Earth ®/weADAPT®: A Pilot Study project (contract number SAIC-06-047-P-R) conducted by Stockholm Environment Institute. The information from this project contributes to Energy Research and Development Division's Energy Related Environmental Research Program.

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ABSTRACT

California is planning adaptation strategies in preparation for anticipated future climate change impacts. A prototype climate change information data delivery and retrieval system was developed using Google Earth to help implement California's first statewide climate change adaptation strategy. This prototype was developed to determine if Google Earth could be used as a platform to effectively deliver complex climate change information to three groups of potential end users: interested stakeholders seeking information on potential climate change impacts in California, planners seeking information for support in decision making and members of the California climate change research community. Various types of software tools, data sets, maps and models were integrated into the Google Earth platform for prototype development. There was a general validation of the utility and efficacy of the Google Earth platform in communicating relevant climate change data to the targeted end users based on direct feedback received at state and local levels. Future recommendations on improving the prototype included technical steps for data organization, technology choices pertaining to the underlying database, and steps for expanding the prototype into the type of information delivery system called for in the *California Adaptation Strategy*, a draft document prepared by the California Natural Resources Agency.

Keywords: climate change, Google Earth, California, adaptation planning

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Introduction

California is undertaking measures in adaptation planning to prepare for future climate change impacts anticipated to occur throughout the state. One aspect of this adaptation planning includes creating a climate change information data delivery and retrieval system for California using Google Earth.

Project Purpose

This project tested the hypothesis that Google Earth could be used as a powerful information platform to effectively deliver complex information about climate change to interested stakeholders seeking information on potential climate change impacts in California, planners seeking information for support in decision making and members of the California climate change research community. These three groups of users were assumed to be interested in potential links between climate change and land-use planning and decision making.

Specific objectives included:

- Making statewide research results available via Google Earth.
- Making local case study information available via Google Earth.
- Conducting a synthesis workshop and other related support activities.

Project Results

A prototype of this system was successfully carried out by the Stockholm Environment Institute (SEI) with joint funding from the California Energy Commission's Public Interest Energy Research (PIER) and Google.org, Google, Inc.'s philanthropic division. Key results of the project included:

- An internet point of contact displaying the selected research results on Google Earth.
- A linked version of Water Evaluation and Planning/Google Earth for the El Dorado Irrigation District case study.
- Appropriate linkage of the analytical tools and Google Earth for selected PIER-funded local climate change case studies.

This Google Earth prototype was well-received. Positive and enthusiastic feedback was received from climate change researchers and personnel from various state agencies. The Google Earth visualizations in communicating climate and other relevant data were generally validated by its utility and efficacy.

Future recommendations for improvements to this initial prototype included suggestions in three general areas: technical steps for data organization, technology choices pertaining to the underlying database and steps for expanding the prototype into the type of information delivery system called for in the draft *California Adaptation Strategy* the *California Adaptation Strategy* prepared by the California Natural Resources Agency.

The study recommended making geospatial data more accessible. For climate data, this specifically entailed providing the data in standard geographic information system (GIS) formats efficiently packed into a single file, serving the data with facilities such as time and spatial subsetting and providing brief examples of how to use the data in the format provided.

The second recommendation used the PostGIS application in Google Earth as the underlying database. Key features of PostGIs included:

1) Efficient storage and retrieval of massive datasets.
2) A complete vector GIS accessed via structured query language.
3) Tight integration with several popular data conversion libraries. PostGIS also has the capacity to generate raw data streams directly from spatial data.

Additional technology recommendations included integrating a powerful statistical package to benefit data aggregation and interpretation, and graphical display and using the Google Earth application programming interface (API), which would allow Google Earth to be integrated within a webpage to provide users with easier access, navigation, and usage of the platform.

Researchers also had several suggestions for expanding the prototype:

1) Transfer the existing prototype to a server that is managed and maintained by the State of California so that SEI's modest single server broadband connection does not become a limitation. Work was underway between SEI and the Energy Commission to respond to this recommendation.
2) Develop a website landing page for the prototype so that it could be identified as a State of California resource. Work was underway between SEI and the Energy Commission to respond to this recommendation.
3) Introduce the prototype in such a way that it would be recognized as a State of California initiative and also recognized as a legitimate tool by the California climate change adaptation community.
4) Focus on adding more content to the prototype through active outreach to the California climate change research community.
5) Produce a series of guidance documents that would instruct individual researchers on how to develop static and animated overlays and how to add data to the interactive multi-scale grid. Organized in-person or on-line training sessions may also be worthwhile.
6) Make an effort to formally assess what the end-user community would like to see in an eventual expansion of the prototype, focusing on both the content as well as the user experience.
7) Select a limited set of end-users who can participate in extensive and formal testing and evaluation of the prototype.
8) Develop a detailed technical plan on how the prototype could be expanded based on the results of the formal testing and evaluation. Use this technical plan to engage an implementation team that could complete the expansion.

9) Implement the expansion of the prototype.
10) Develop and implement a plan to publicize the availability and utility of the information delivery system, developed in accordance with the draft *California Adaptation Strategy*. This plan should include efforts to attract both end-users as well as potential contributors of additional relevant climate change information.
11) Monitor use, evaluate performance and continue to innovate.

Project Benefits

This work will benefit California as it prepares for future climate change impacts expected to affect the state. The Google Earth platform could serve as a useful tool for interested stakeholders and decision makers to effectively deliver and retrieve relevant climate data and other types of relevant data. Ultimately, all Californians will benefit from further development and use of the Google Earth platform for statewide climate adaptation planning.

CHAPTER 1: Introduction

This report summarizes progress made by the Stockholm Environment Institute (SEI) in developing a prototype climate change information presentation and retrieval system for California using Google Earth. The work was carried out as part of a joint funding initiative by the Public Interest Energy Research (PIER) Program of the California Energy Commission (Energy Commission) and Google.org, Google's philanthropic arm. Work on this effort took place between the autumn of 2008 and the summer of 2009 and included substantial investments in technology development along with periodic interactions with key actors within state government, the California climate change research community, and interested stakeholders.

From its outset this project was about testing a hypothesis, namely that Google Earth could be used as a platform to effectively deliver complex information about climate change to stakeholders and decision-makers. This hypothesis is summarized in the following assertion included in the original project Statement of Work.

> *Successful integration and dissemination of [climate change] information into decision making is dependent on creating flexible and scalable tools and methodological frameworks that enable communication of data and analysis in a way that is both useful to researchers and accessible to decision makers. Google Earth is one of the most exciting examples of these evolving technologies.*

From within the full spectrum of climate change information, this project placed particular importance on information relevant to the assessment of potential climate change impacts and the evaluation of potential adaptation actions. This focus was justified by Governor Schwarzenegger, who in a November 2008 Executive Order charged state government:

> *to initiate California's first statewide climate change adaptation strategy that will assess the state's expected climate change impacts, identify where California is most vulnerable and recommend climate adaptation policies by early 2009.*

In response to this executive order and in parallel with work on the current project, the California Natural Resources Agency completed a draft of the *California Adaptation Strategy* that included the following recommendation.

> *By September 2010, a user friendly web-based map and interactive website will be developed and regularly updated by the California Energy Commission to synthesize existing California climate change scenario and climate impact research and to encourage its use in a way that is useful for local decision-makers.*

This draft recommendation provides an extremely useful and important context within which to evaluate the progress made by Stockholm Environment Institute over nearly a year of effort. It motivates consideration that the prototype system developed by Stockholm Environment Institute may eventually be expanded.

At the outset of the project Stockholm Environment Institute agreed to complete three broad tasks designed to test the hypothesis that Google Earth could provide a powerful information delivery platform for decision makers in California. These included:

- Task 1 Making statewide research results available via Google Earth
- Task 2 Making local case study information available via Google Earth
- Task 3. Conducting a synthesis workshop and other related support activities

As is the case with any technology development effort, the current project unfolded in a manner that was informed by these initial tasks, but was also responsive to feedback generated and experience gained over the course of project implementation. Rather than report on each task individually, in this report the authors trace the development of the Google Earth prototype from the process of (i) selecting appropriate data sets for presentation, (ii) developing the initial technical design, (iii) presenting the selected information based on this technical design, and (iv) assessing the utility of the prototype as a means for developing recommendations for further development of the prototype.

While reporting on the process of technology development, however, it is useful to keep in mind the tangible deliverables that were promised to the Energy Commission by Stockholm Environment Institute at the conclusion of the projects. Outside of those deliverables related to meeting attendance and reporting, these were:

- An internet point of contact displaying the selected research results on Google Earth.
- Linked version of WEAP/Google Earth for the El Dorado Irrigation District case study.
- Appropriate linkage of the analytical tools and Google Earth for selected PIER funded local climate change case studies.

Reference to these tangible deliverables is made at various points in the current report. The most important thing to keep in mind in reading this report, however, is that Stockholm Environment Institute was charged with developing a prototype of a data delivery and retrieval system based on Google Earth technology. This was the researcher's goal and their important accomplishment.

CHAPTER 2:
Selecting Appropriate Data Sets

Task 1 in the original Statement of Work focused on making statewide climate change adaptation relevant data and information available via Google Earth. In October 2008, a series of conference calls were initiated between Stockholm Environment Institute, the Energy Commission, the Natural Resources Agency and Google.org to discuss which statewide data sets might be included in a prototype information delivery system based on Google Earth. This conversation was guided by the definition of a set of hypothetical end users of the proposed technology. This set included three target individuals; the first was an interested stakeholder seeking insights on potential climate change impacts in California. The second was a planner, presumably from within a government entity, seeking to gather information to support decision making. The third and final individual was a member of the California climate change research community. Recognizing that it would be impossible to gather the totality of information that may be of interest to these three hypothetical end-users into a prototype system, a further hypothetical construct was posited, namely that these individuals would be interested in potential links between climate change and land-use planning and decision making.

In response to this hypothetical set of end-users, Stockholm Environment Institute selected the following sets of statewide information for integration into the Google Earth prototype.

- Historical climate information
- Future climate projections
- Current population data
- Future population projections
- Current land cover and terrestrial habitat assessments
- Current fire risk and threat
- Future fire risk projections

Table A.1 in the appendix to this report summarizes the specific datasets, data characteristics and sources.

Task 2 in the original Statement of Work focused on the presentation of climate change information relevant to local case studies via Google Earth. The motivation for this task was that while statewide data sets are, by definition, comprehensive, they may not contain the sort of local resolution to support adaptation planning and decision making at the level of a city, a county, or some other local government entity. After a series of discussions with the Energy Commission, the Natural Resources Agency and Google.org, SEI decide to focus on exploring how Google Earth could be used to present information useful in the following two regional settings:

- Water resources management in the American River watershed
- Coastal zone management in the San Francisco Bay region

Having selected these data sets for integration into the proposed Google Earth prototype, attention turned to developing an initial technical design for the proposed information delivery and retrieval system.

CHAPTER 3:
Initial Technical Design

Based on the characteristics of the selected data, SEI initiated work on a technical design that could support the representation and retrieval of this information. Three key characteristics of the selected data, and likely any other relevant data sets that may be added to the prototype in the future, proved influential in shaping the design process.

- **Different datasets are available at different resolutions and projections.** For example, the downscaled climate projections and fire projections were available at 1/8th degree of latitude/longitude (approximately **7.5 miles x 7.5 mile** a side) grid size, while the landcover data was available on a **100 meter x 100 meter** grid.
- **Different datasets are available in different formats.** For example, the historical climate data was available in netcdf format, the landcover data in Arc GRID format, and the projected fire data as one shapefile with a separate attribute table with very specific coding.
- **Time is represented differently in different data sets.** For example, current land cover data are time invariant while future climate projections vary month by month over a period of 100 years.

The implication of these characteristics is that the authors would have to impose some structure within the prototype design, to which data in various resolutions, formats and time characteristics would need to conform. Without such a structure the project would devolve into an effort to post disparate data sets on Google Earth, a very mechanical process that would not advance the effort to design prototype data presentation and retrieval system. In an attempt to avoid such a mechanical exercise the authors conducted an exhaustive survey of software technologies that could be deployed to capture the following desired features of the prototype product:

- Pre-processing of geospatial data from many different GIS formats
- A database with geospatial capabilities that could also dynamically export to KML (the format that Google Earth uses)
- Cost-effectiveness
- Rapid deployment
- Ability to integrate the several different software choices

No single stand-alone technology – a GIS for example - could meet all of the above needs. This realization led us to a set of technology tools that were implemented on a Linux server set up by SEI for this project. The application framework relies on a series of low-level libraries (GDAL, Proj4, GEOS and Postgresql) for data conversion, raster and vector GIS operations and efficient storage of very large data files. These libraries support a suite of applications (GRASS GIS, PostGIS, R, and PHP) that form the core of Google Earth file generation and styling functionality. The integration of these various tools into the final prototype is depicted graphically in Figure 1.

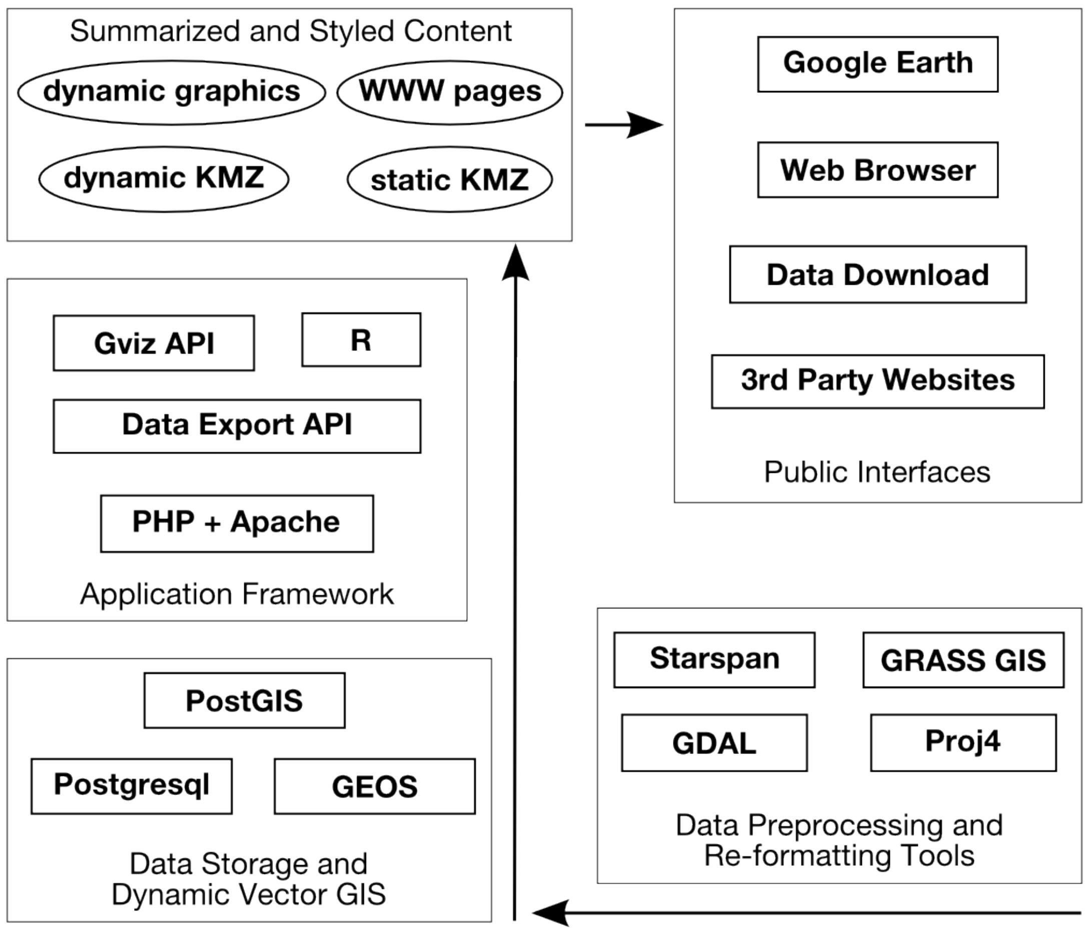


Figure 1: Technology Integration and Process Flow.

Source: Stockholm Environment Institute.

This figure demonstrates the suite of open source tools used to support data processing. These tools were selected because they are readily installed on any operating system (Linux, Macintosh and Windows), are well-documented and are free to use or modify.

Table 1: Selected Software Tools and the Development and Implementation of Google Earth Applications.

These tools were selected because they are readily installed on any operating system (Linux, Macintosh and Windows), are well documented and are free to use or modify.

Software	Use in the project
Postgresql	data storage and query facilities http://www.postgresql.org/
Postgis	spatial extension to Postgresql, vector GIS operations via SQL http://postgis.refractions.net/
Starspan	Data pre-processing, raster-vector integration http://starspan.casil.ucdavis.edu/doku/doku.php
Gdal/ogr	Data conversion, subsetting, import/export http://gdal.org/
R	Dynamic graphics and summary statistics http://www.r-project.org/
GRASS	Data pre-processing, static kmz generation http://grass.osgeo.org/
PHP	Application "glue", KML styling http://www.php.net/
Apache	WWW server http://www.apache.org/
Gviz API	Google's visualization API, dynamic charts http://code.google.com/apis/visualization/
Google Earth 5.0	Visualization platform http://earth.google.com/

A final component of the initial technical design was to imagine different modes for viewing and interacting with the selected data via Google Earth. By their very nature different datasets call for different modes of presentation in order to convey the information content to a target end-user in the most direct and intuitive manner. Building on the experience gained during the development of weADAPT (http://weadapt.org), a set of tools designed by SEI and partners to support an on-line climate change adaptation community, the authors proposed several potential presentation modes. These were vetted during a number of meetings convened by the contract manager with researchers and agency staff. Following this vetting process the researchers selected the following modes of presentation to deliver the selected information within the Google Earth prototype.

(i) **Interactive, multi-scale grid** – A presentation mode whereby the user can see both summary and detailed information on various spatially distributed data sets at a statewide scale using a nested set of grids available at three scales, with the ability to download information of interest for a particular location in California.

(ii) **Static overlays** – A presentation mode whereby spatially variable and temporally static information for California is presented as a color coded map overlying either the entire State or some relevant region.

(iii) **Animated overlays** – A presentation mode whereby spatially and temporally variable information for California is presented as a time coded animation of color coded maps overlying either the entire State or some relevant region.

(iv) **Impact/Adaptation studies** – A presentation mode whereby icons representing various climate change studies conducted in California are placed on the State with links to an on-line database of corresponding *.pdf files.

(v) **Model publication** – A presentation mode whereby the structure of an impact assessment model, along with key model input and results, are overlain on some relevant region of California.

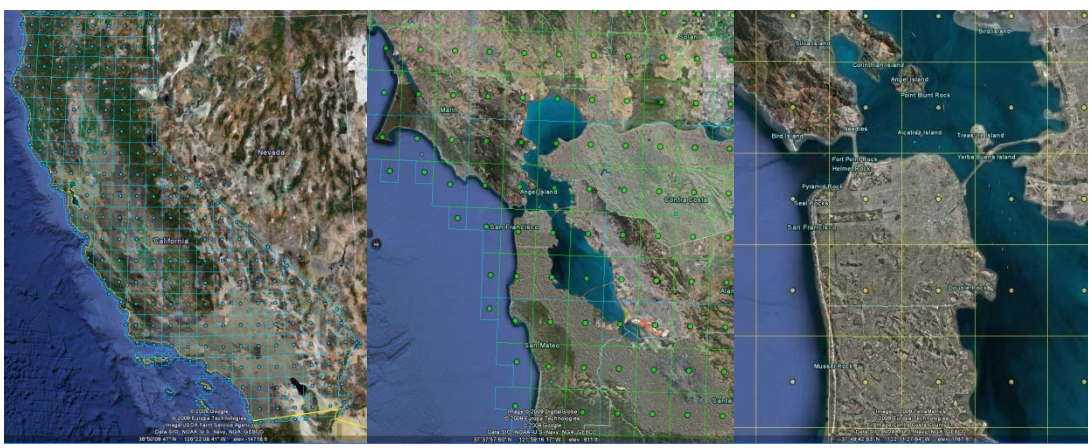
The following section details how these presentation modes were used to present the data sets selected for introduction into the Google Earth prototype.

CHAPTER 4:
Presentation via Google Earth

This section of the current report highlights the use of the various presentation modes to present some of the selected data sets. The reader is referred to the website developed for this project (http://wikiadapt.org/index.php?title=Google_Earth_Project_California) in order to access all of the selected data sets. *This website constitutes one of the primary deliverables (i) for the current project.*

4.1 Interactive, Multi-Scale Grid

The interactive, multi-scale grid application provides interlinked data access to datasets that are included in an application database. In the prototype, these data sets included information on future climate projections, current land cover and terrestrial habitat assessment, current fire risk and threat, and future population projections. These data are presented via a series of nested grids over California which have resolutions of 1/2, 1/8, and 1/16 degree. This nested structure is shown in Figure 2.



(A) **(B)** **(C)**

Figure 2: Nested, Interactive Grid Structure Over California at Resolutions of 1/2 (A), 1/8 (B), and 1/16 (C) Degrees.

Source: Stockholm Environment Institute

By clicking on the node at the center of any grid cell, the user will gain access to selected data included in the application database via series of linked charts and tables (Figure 3 for future climate projections and current land cover, terrestrial habitat assessment, fire risk and fire threat over the San Francisco Financial District). The information contained in these charts and tables is also available for download via the application. Future population projections are also available in this mode, although this is not shown in Figure 3.

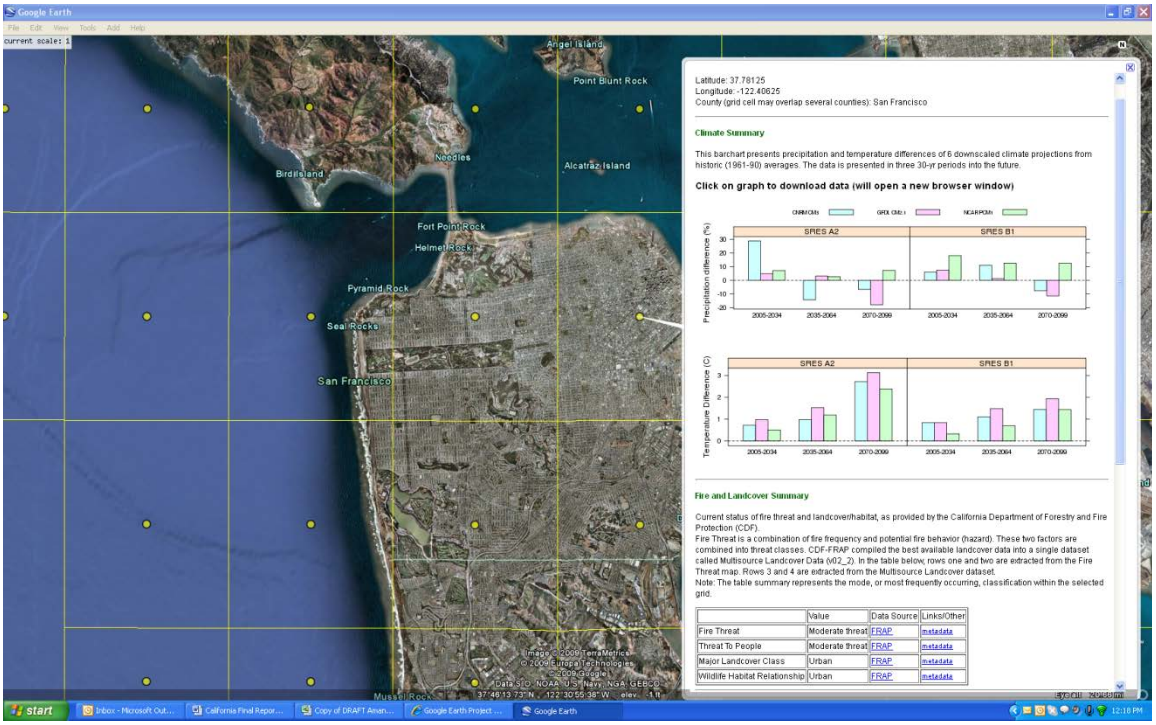


Figure 3: Example of Data Presentation Via the Interactive, Multi-Scale Grid.

Source: Stockholm Environmental Institute

It is worth noting, however, that some datasets like current fire threat, landcover and terrestrial habitat assessment data occur at very fine resolution (100m in this example). Access to the actual data values on Google Earth would be prohibitive given the extremely small grid cells. Spatial aggregation is provided for these data; for example, the modal value (most frequently occurring class) within the grid cell in question is given (lower table in Figure 3). Access to the underlying data is provided via sub-grid cell histograms available by navigating within the database-linked Google Earth balloon. Graphics in the balloons can also invoke temporal aggregation, as is the case with the bar chart summaries for future climate projections (upper graph in Figure 3). Access to the underlying time series is also provided by navigating within the Google Earth balloon.

In addition to the issue of aggregation, feedback from the climate change research community highlighted the need to take precautions to ensure that users would be aware of the actual resolution of the data. To this end, the researchers incorporated two features in this interactive, multi-scale grid. First, only climate data is currently accessible at coarse (1/8, 1/2 degree) scales (corresponding to blue and green colored grids). This prevents misleading aggregation of landcover, habitat and fire data that cross ecosystem regimes. Second, if the user zooms in to a Google Earth resolution finer than one 1/16 degree grid cell, a warning message is displayed and no data is provided. These conventions should help the end-user better understand the spatial resolution of available data, and its implications.

The key feature of this Google Earth application in terms of the potential to scale up the current prototype is that the graphs and tables included in the Google Earth balloons are developed via serve-side scripting that query the application database, create the graphics, and produce the balloons on the fly. This architecture could be replicated for other data sets that the eventual user community would like to see added to the application database. All that would be required would be to organize a new dataset according to the structure of the nested grid, to develop appropriate graphics and tables built on the new data, and to modify the Google Earth balloon design to accommodate this new content. Once this was complete, the new data would be available to the end-user community via the interactive, multi-cell grid.

4.2 Static Overlays

The static overlay presentation mode was developed in order to allow for the display of thematic maps of spatially variable and temporally constant data within Google Earth. The development of a static overlay is a fairly mechanical exercise as most GIS systems currently allow for the presentation of data in the format that is used by Google Earth. Data sets that have been made available as static overlays include historical climate data, current landcover and terrestrial habitat assessments, current fire threat and future fire risk projections, and sea level rise inundation risk in the San Francisco Bay Area. An example of a statewide static overlay available in the prototype is shown in Figure 4, which shows the projected increase in burned area within a grid cell relative to the historical baseline under some future climate regime at some point in the future.

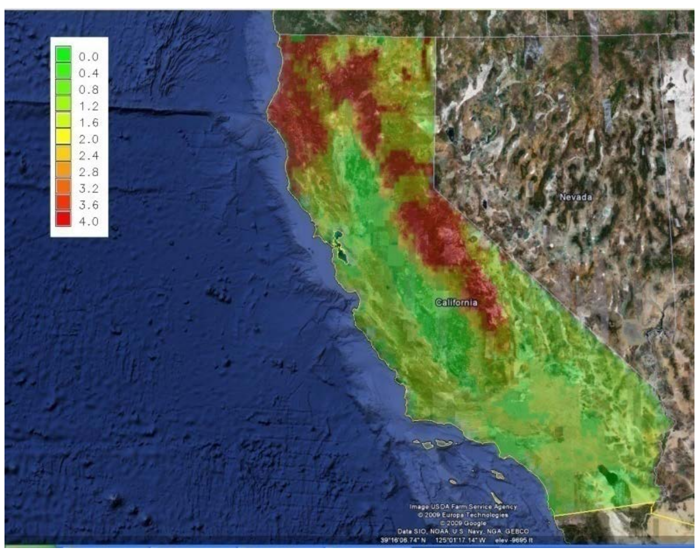


Figure 4: Times Increase in Burned Area in 2085 Relative to the Historical Baseline Based on Downscaled GFDL-CM21 Model Output Under the A2 Emission Scenario.

Source: Stockholm Environmental Institute

Local data sets can also be presented as static overlays, such as potential inundation maps developed by the USGS from the San Francisco Bay Area for different levels of sea level rise, as shown in Figure 5. *The presentation of this data constitutes one of the primary deliverables (iii) for the current project.*

Figure 5: San Francisco Bay Inundation Under Different Sea Level Rise Scenarios.

Source: Stockholm Environmental Institute

Since each static overlay is stored in a unique *.kml file, end users would have the flexibility in an eventual expansion of the prototype to add any other content.[2]

4.3 Animated Overlays

Whereas information presented in static overlays is spatially variable and temporally static, other information contains a variable temporal dimension, making it unsuitable for presentation via a static overlay. To present spatially and temporally variable information the researchers developed the animated overlay mode which has been applied to historical climate information, future climate projections, and the simulated change in snow accumulation in the American River watershed. These animated overlays are a bit more complicated to construct than static overlays in that a series of spatially variable, time unique data sets need to be strung together in sequence. Within the prototype the researchers have demonstrated the use of the grid that was used in the interactive, multi-scale mode as a structure for the animation as well as less regular spatial structures that can be defined by someone contributing an animated overlay in the future according to the characteristics of their particular data set.

Figure 6 depicts an animated overlay of changes in downscaled future late winter-early spring temperatures across California as predicted using the GFDL model in 2025 and 2075 (the actual animation includes the complete time series). The regular grid utilizes the same 1/8 degree cells as the interactive, multi-cell mode, with the color coding occurring as the animation runs through a series of calls to the application database. What is particularly exciting about this application in the prototype is that it would be relatively easy to add other temporally variable data to the database and to develop associated animated overlays.

(A) (B)

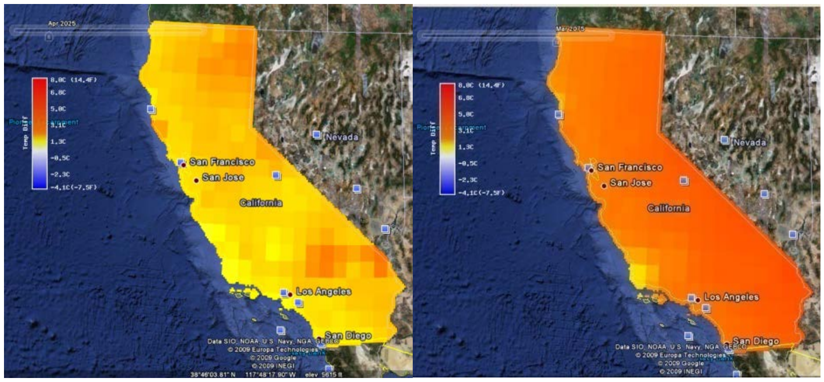
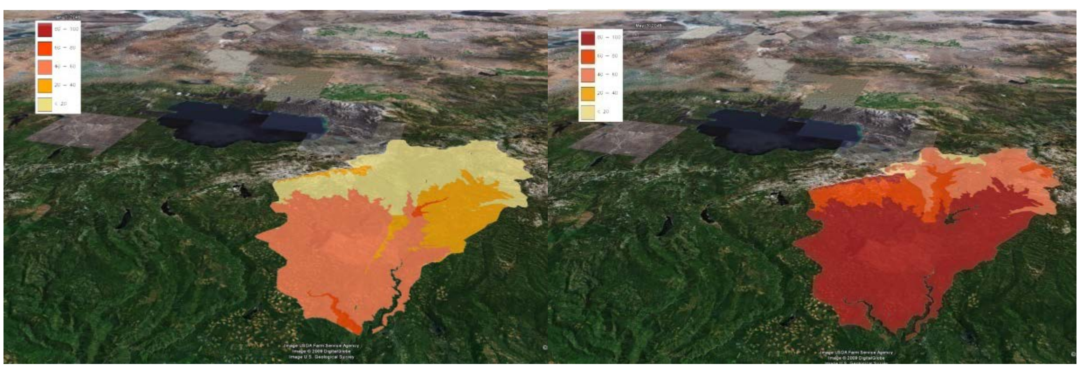


Figure 6: Projected Late Winter, Early Spring Temperatures in 2025 (A) and 2075 (B) According to Downscale Results From the GFDL Model.

Source: Stockholm Environmental Institute

Figure 7 presents an animated overlay based on a more locally relevant set of data, namely the change in average weekly winter and spring snow accumulation, relative to the historical period, predicted in the period between 2025 and 2050 using downscaled climate data from the GFDL model run under the A2 emissions scenario (the actual animation includes all time periods). The deeper the color, the greater the simulated loss in snow pack, with the brick red color corresponding with an 80 to 100 percent loss in snow pack. The data used to construct this animated overlay were developed by SEI in collaboration with the El Dorado Irrigation District and are structured based on sub-watershed boundaries rather than on a regular grid.



(A) (B)

Figure 7: Change in Weekly Average Snow Accumulation Relative to the Historical Baseline in the American River Watershed in Early January (A) and Early May (B).

Source: Stockholm Environmental Institute

The eventual development of local, irregular animation such as the one depicted in Figure 7 will require some level of additional work on the part of an end-user who would like to contribute data to an eventual expansion of the prototype as it would be impossible to anticipate the infinite range of database structures into which data may be organized.

4.4 Impact/Adaptation studies

Over the course of the past decade, a substantial investment has been made by the Energy Commission in the support of climate change impact research. The most tangible output of this investment is a series of excellent reports available to the general public via download from an Energy Commission website. This presentation mode was developed to demonstrate how these reports might be given a spatial context within the Google Earth prototype. Figure 8 depicts the posting of a small set of Energy Commission reports as spatially referenced icons within California. By clicking on an icon the end-user will be provided with the report abstract in a Google Earth balloon and a link to download the full document.

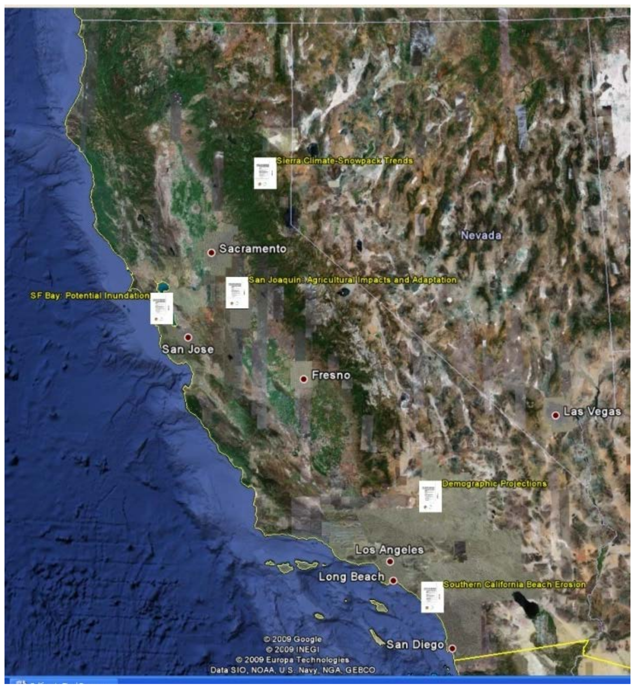


Figure 8: Selection of Spatially Referenced Energy Commission Reports.

Source: Stockholm Environmental Institute

There is enormous potential to expand this presentation mode by linking all spatially relevant reports to the prototype. This will be of service to an end-user in a particular region of California who is looking for locally relevant information to support decision making, something which may not be self-evident in perusing a list of report titles.

4.5 Model Publication

As a great deal of relevant climate change information involves future projection, as opposed to historical data that has been observed and recorded in the past, the use of models is pervasive. The future climate projections, for example, are in fact output from general circulation models of the coupled land-ocean-atmosphere system. As these data are model outputs, and not measurements, there is reason to believe that providing an end-user access to the underlying models used to develop future projections could be helpful in terms of supporting the decision making process. The model publication presentation mode was developed to explore this possibility.

The target model for this effort was an application of the Water Evaluation and Planning (WEAP) system developed for the El Dorado Irrigation District. WEAP is a software product developed by SEI that is in common utilization by water managers around the world that seek to identify potential water management impacts from climate change and to evaluate potential adaptation options. As part of this project, SEI modified the software to allow for the publication of the model nodes and links to Google Earth as shown in Figure 9. This publication places the objects used to construct the model in their proper spatial position.

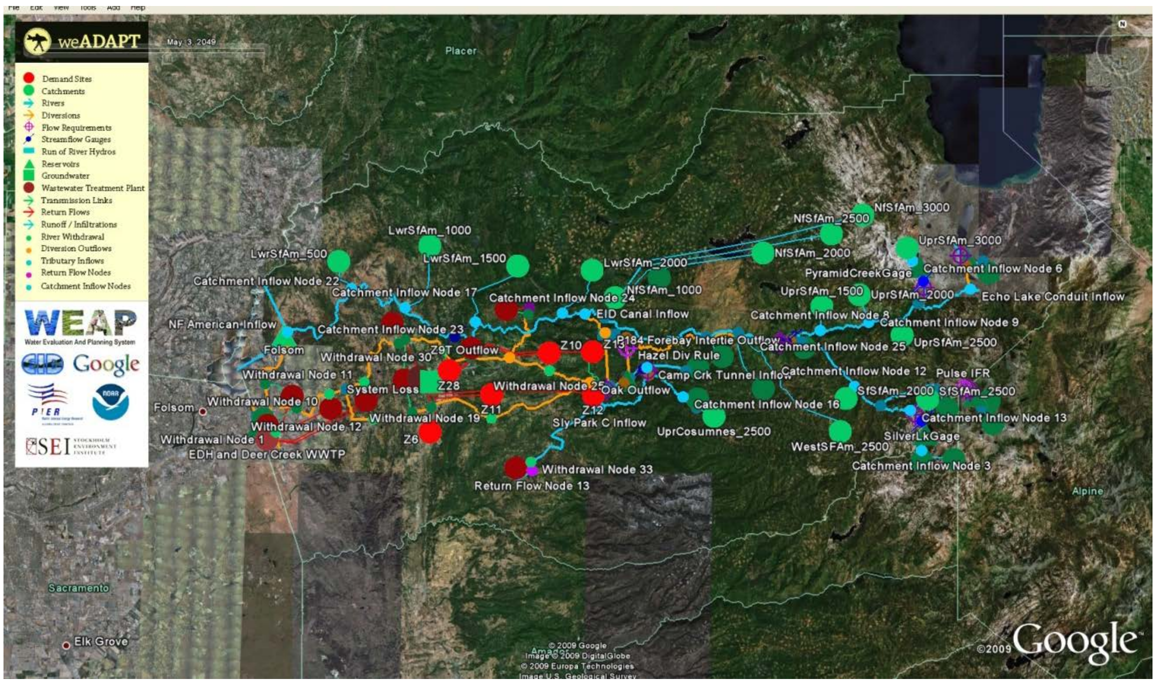
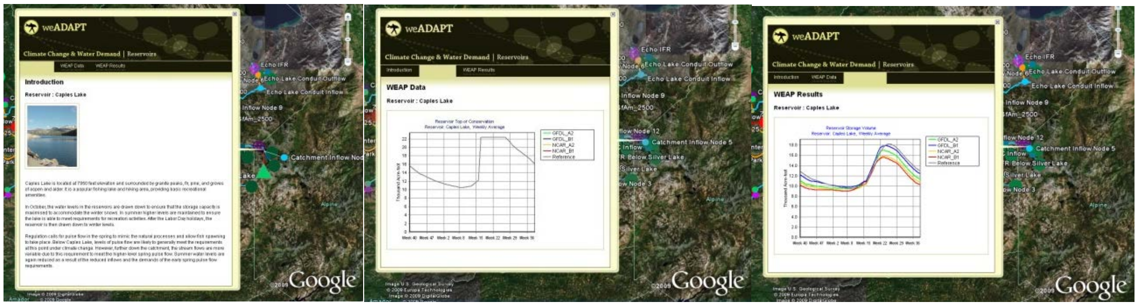


Figure 9: WEAP Application for the El Dorado Irrigation District in Google Earth.

Source: Stockholm Environmental Institute

In addition to publishing the model link and node structure, however, it would also be useful to publish key information about each model object, key input data associated with each model object, as well as key model output. This functionality was also added to WEAP as shown in Figure 10, in this case for the Caples Lake Reservoir model object in the El Dorado Irrigation District WEAP application. The Google Earth balloon associated with this object includes background information on Caples Lake, information pertaining to the reservoir guide curve, a key model input, and information on a key model output, the average weekly reservoir storage under a range of future climate projections. The selection of which information to include in each balloon is made by the model developer for each object in the application.



(A) **(B)** **(C)**

Figure 10: Publication of Relevant Background Information (A), Model Input (B) and Model Results (C) From the EID WEAP Application Via Google Earth.

Source: Stockholm Environmental Institute

This is perhaps the most complicated presentation mode developed as part of the prototype as it requires the cooperation of the developers of models used to generate climate change relevant information. Still, it is also perhaps the most important mode as it could serve to open up models for decision makers in a manner that illuminates the assumptions used to develop these important tools. This was the case when the published WEAP application was presented to stakeholders and decision makers associated with El Dorado Irrigation District who stated that providing access to the model via Google Earth was extremely helpful in assessing the information generated by the tool. *The publication of the El Dorado Irrigation District WEAP application constitutes one of the primary deliverables (ii) of the current project.*

CHAPTER 5:
Assessing the Utility of the Prototype

As part of the researcher's efforts to develop the Google Earth prototype, the researchers engaged in a number of meetings designed to assess the tools potential utility and to develop ideas for eventual expansion. At the state level, the Energy Commission project manager, Mr. Guido Franco, facilitated a series of structured interviews with PIER funded climate change researchers and personnel from various state agencies. For a local level case study, SEI leveraged a grant from National Oceanic and Atmospheric Administration to organize a similar exercise with stakeholders and managers within the El Dorado Irrigation District. This section summarizes the feedback received.

The majority of the direct feedback that the researchers received at state and local scales was very positive and enthusiastic. The following responses were heard.

- A general validation of the utility and efficacy of the Google Earth visualizations in communicating climate and other types of data.
- A specific validation of using different presentation modes.
    - Climate data is presented both in an interactive manner through the interactive gridded application, as well as via animated overlays. The first allows the user to access place-specific climate information; the second provides a state-level visual perspective on spatial and temporal patterns of climate variability.
    - Local El Dorado Irrigation District decision makers and area residents were extremely enthusiastic about both the statewide layers as well as El Dorado Irrigation District specific layers. The strategy of using multiple methods of presentation resonated well with all. For example, the El Dorado Irrigation District -WEAP model, including a Google Earth overlay of the water resources model with rich content including photographs, videos and model result graphics, was greeted enthusiastically.

There were, however, some concerns expressed by the state level scientific community related to (i) communicating the notion of uncertainty to both the decision maker as well as the general audience, and (ii) providing information appropriate to its resolution. There was also a concern expressed within state agencies pertaining to liability and appropriate legal clearances for making this information so readily available, a concern that was shared to some extent by the scientific community as well, especially with regards to fire and sea level rise information.

From one perspective, the concern regarding liability can be seen as a measure of the success of this effort – *the concern was a reaction to the efficacy of the communication achieved*. It is worth noting, however, that all the data and all of the tools the researchers used to construct the prototype are publicly available free of charge. In theory, anyone with a modicum of technical sophistication could repeat the steps the researchers took in developing the prototype. Nonetheless, acknowledging this concern, the researchers took steps to include a disclaimer in the overview section of all of the presentation modes included in the prototype. In preparation for an eventual expansion of the prototype, additional attention should be paid to develop the most appropriate disclaimers possible.

Uncertainty in model projections was communicated in several ways. When possible, more than one projection was presented. The authors included six climate projections in the prototype and presented these in various ways, thus visually communicating the differences between projections. The authors also developed motion charts based on the future climate projections using the Google Visualization Application Programming Interface. These charts readily display the variability between different projections, as well as the inter-annual variability within a single climate projection. The authors also presented ranges of future population projections rather than a single mean expectation. Regarding the data resolution concern, the authors described how they addressed this topic earlier in the report.

CHAPTER 6:
Recommendation and Conclusions

Based on the experience gained in developing the prototype and from subsequent interactions with the climate change research community, State agency personnel and implicated stakeholders and decision makers, the authors will present recommendations of various types. The first pertains to technical steps that could be taken in organizing relevant data to facilitate the eventual expansion of the prototype. The second set of recommendations pertains to the underlying technology used to present this information. The final set of recommendations pertains to the next steps that could be taken to scale up the prototype into the sort of data delivery system called for in the draft *California Adaptation Strategy*. The researcher's expectation is that this system could also serve as a repository for the output from future research that will be conducted by the California climate change research community.

6.1 Making geospatial data more accessible

Preprocessing of the different selected data represented a substantial time investment. The original data was compiled and served by different entities, was of different types, and was served in different formats, which accounts for the large time investment in pre-processing steps. To some extent this is unavoidable because the different types of data included in the prototype were gathered from different sources. However, some level of standardization among those wishing to contribute data to the eventual expansion of the prototype would be helpful. Particularly if someone from a State agency will be responsible for getting contributed data into the proper format (an alternative would be to have those contributing data do so via a set of standard protocols).

For climate data, the authors recommend the following minimum considerations for data that will be included in an eventual data delivery system:

(i) Provide the data in standard GIS formats that are efficiently packed into a single file.

(ii) Serve the data with facilities such as time and spatial subsetting.

(iii) Provide brief examples of how to use the data in the format provided.

A good example of climate data provided in this manner are the statistically downscaled climate projections served out of the Santa Clara University-hosted site:

http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#About

For static maps, such as the current land cover overlay, the choice of format seems less important. The researchers did find, however, that the California Department of Forestry and Fire Protection's GIS data service (http://frap.cdf.ca.gov/data/frapgisdata/select.asp) was very well documented and designed and could serve as a model for how data could be organized for eventual integration into the data delivery system.[3] In general, Shapefiles (for vector) and GeoTiff (for raster) data should suffice.

6.2 Technology for Google Earth visualization

As previously stated, no single stand-alone GIS or other technology exists to generate the presentation modes included in the prototype. This project has demonstrated that an open source solution that uses several different tools works well to meet the needs of the data delivery and retrieval system. The integrated suite of tools the researchers deployed is cost-effective, robust and efficient. Here the authors present several key recommendations on technology choices.

Beyond pre-processing, the choice of an underlying database played a pivotal role. PostGIS has several key features that make it an ideal choice for this task: 1) efficient storage and retrieval of massive datasets, 2) a complete vector GIS accessed via SQL, and 3) tight integration with several popular libraries (e.g. GDAL, PHP, Python). In addition, PostGIS has the capacity to generate raw KML and GeoJSON data streams directly from spatial data.

Integrating a powerful statistical package like R into the researcher's toolkit allows sophistication in data aggregation and interpretation, as well as graphical display. This is a feature that the scientific community may particularly appreciate as they prepare information for integration into, and eventual expansion of, the prototype. The researchers also developed one example of a Google visualization API, creating a motion chart, and there are several other Google tools that could be more fully utilized to enhance the information content of data presentation.

Also note that while the applications the researchers developed in Google Earth are compelling, they are not self-guided. That is, the selection of Google Earth itself has three potential ramifications: (i) Google Earth needs to be installed, (ii) a good internet connection is needed, and (iii) the user needs to be comfortable with the basic navigation and use of Google Earth.[4] It may be worth considering using the Google Earth API, which allows Google Earth to be integrated within a webpage, as part of any future development, as part of a response to these issues.

6.3 Suggestions for Expanding the Prototype

Several key questions have emerged from this project, regarding if and how the Google Earth prototype could be scaled up, potentially to include key findings from all PIER-supported climate change research and other relevant sources. The authors provide the following recommendations to support such an effort. These recommendations are listed in what seem to be a logical order on the path toward developing the information delivery system called for in the draft *California Adaptation Strategy*.

1. Transfer the existing prototype to a server that is managed and maintained by the State of California so that the limitation of the single server connected to the internet through SEI's modest broadband connection does not become an impediment. Work is currently underway between SEI and the Energy Commission to respond to this recommendation.

2. Develop a website landing page for the prototype that conforms to the design and performance of a State of California webpage so that the prototype can be properly

identified as a State resource. Work is currently underway between SEI and the Energy Commission to respond to this recommendation.

3. Roll out the State hosted and introduced prototype so that the tool begins to gain some legitimacy in the eyes of the California climate change adaptation community. For this prototype to further develop, the impression needs to be conveyed that this is a State of California initiative, not an SEI project. Planning is underway to officially launch the prototype as part of the upcoming release of the final version of the *California Adaptation Strategy*.

4. Focus on adding more content to the prototype through active outreach to the California climate change research community. Let them know that the tool is available for them to post static and animated overlays derived from their research through the prototype. Attention should also be placed on adding information from the research community within the interactable, multi-scale grid application database. This will require close coordination with the research community so that the scripts required to create graphical content based on these data, and to populate Google Earth balloons with this content, can be developed.

5. In parallel with this aforementioned outreach effort to the California climate change research community, a series of guidance documents need to be produced that will instruct individual researchers how to develop static and animated overlays and to add data to the interactive multi-scale grid. It may also be worthwhile to organize in-person or on-line trainings to assist the research community in contributing information to the prototype.

6. While the content within the prototype is being enriched, make an effort to formally assess what the end-user community would like to see in an eventual expansion of the prototype. This assessment should focus on both content and the user-experience. Using the co-funding from Google.org made available for this project, SEI worked in Kenya to organize a workshop to elicit from a broad spectrum of stakeholders their ideas on what a climate change information delivery and retrieval system might entail (*data types, modes of presentation, utility for adaptation*). The authors suggest that a comprehensive knowledge mapping exercise, along the lines of the Kenya experience, be considered in California.

7. From amongst the individuals involved in the assessment, select a more limited set of end users who can engage in extensive and formal testing and evaluation of the prototype. Ideally this testing will occur once the richness of the available content has been expanded through contributions from the research community so that the target end users will be able to develop a more complete vision of how the eventual expanded prototype could be used to support climate change adaptation planning.

8. Based on the results of the formal testing and evaluation, develop a detailed technical plan on how the prototype could be expanded in advance of the deadline set in the draft *California Adaptation Strategy*. It is the researcher's opinion that this technical plan should

include the use of the Google Earth API so that the eventual end user will not be required to have the standalone version of Google Earth installed on their computer. Use this technical plan to engage an implementation team that can complete the expansion.

9. Implement the expansion of the prototype.

10. Develop and implement a plan to publicize the availability and potential utility of the expanded prototype, which by this time will have been transformed into the actual information delivery system called for in the draft *California Adaptation Strategy*. This plan should include efforts to attract both end users as well as potential contributors of additional relevant climate change information.

11. Monitor use, evaluate performance, and continue to innovate.

CHAPTER 7: Conclusions

At the conclusion of nearly a year of effort the authors are in a position to state with confidence that the researchers have made great strides toward making the information needed to support climate change adaptation planning in California more available to key stakeholders and decision makers. The steps the researchers have made are necessary to allow required planning to move forward in the face of what could potentially be the greatest upheaval in resource context for the author's collective social development in California. This step is not sufficient, however, as much work needs to be done to expand the current prototype into a tool that can support climate change adaptive planning. SEI stands ready to join with the Energy Commission and other branches of State government, as appropriate, in order to meet the challenge laid out in the California Adaptation Strategy.

Appendix A: Selected Data

Climate			
	Scope	**Source**	**Format**
Historical	Statewide Average monthly *(1961-1990 average)* Temperature and Precipitation	Ed Maurer http://www.engr.scu.edu/~emaurer/data.shtml http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html	netcdf 1/8 degree resolution
Climate projections[1]	Statewide Annual Time series *(2010-2100)* 6 projections *(3 GCM, 2 emissions scenarios)* Temperature and Precipitation	Ed Maurer http://www.engr.scu.edu/~emaurer/data.shtml	netcdf 1/8 degree resolution
Fire, Landcover and Habitat			
Fire Threat	Statewide	California Department of Forestry	ESRI Arc GRID 100m resolution
Projected Fire	Statewide *12 scenarios of modeled future burned area*	Tony Westerling UC Merced	Shapefile with custom table
Habitat	Statewide	CDF	ESRI Arc GRID 100m resolution
Land cover	Statewide	CDF	ESRI Arc GRID 100m resolution
Population			

5 At the beginning of application development for climate data, the newest CCCC climate projections were not available in formats that could be included in this application in a timely manner.

County population projections	Statewide By county 2005 to 2100 projections every 5 years	Public Policy Institute of California *Data Provided by Researchers workspace*	MS Excel file
Urban population projections	Statewide 2010 to 2100 projections every 5 years	Lawrence Livermore National Laboratory *Data Provided by Researchers workspace*	Arc/Info rasters
Sea Level Rise			
Google Earth application	Bay Area	Noah Knowles, USGS	Kml/Kmz
Google Maps	Bay Area and CA coast	Pacific Institute	
Water Resources: El Dorado Irrigation District (EID)			
WEAP model on GE	EID	SEI *Outcome of Water Resources Modeling efforts*	WEAP to kml
Snow Impacts	SFk American river	SEI *Output of Water Resources Modeling efforts*	Kmz animation of WEAP output